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IC FABRICATION USING ELECTRON-BEAM TECHNOLOGY.(U)
APR 79 G L VARNELL, S CHIANG, J REYNOLDS DAAB07-76-C-8105
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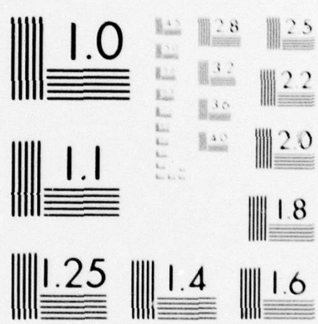


MICROCOPY RESOLUTION TEST CHART

LEVEL II

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# Research and Development Technical Report

DELET-TR-76-8105-9

AD A068656

## IC FABRICATION USING ELECTRON-BEAM TECHNOLOGY


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April 1979

Ninth Quarterly Report for Period 1 September 1978 - 1 December 1978

DISTRIBUTION STATEMENT

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Prepared for:
ELECTRONICS TECHNOLOGY & DEVICES LABORATORY

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| 19 REPORT DOCUMENTATION PAGE | | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|---|
| 1. ~~REPORT NUMBER~~ 18 DELET TR-76-8105-9 | 2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER 9 |
| 4. ~~TITLE (and Subtitle)~~ 6 IC FABRICATION USING ELECTRON-BEAM TECHNOLOGY. | | 5. TYPE OF REPORT & PERIOD COVERED [redacted] Quarterly rept. no. 9, 1 Sept[redacted] – 1 Dec[redacted]78 |
| | | 6. ~~PERFORMING ORG. REPORT NUMBER~~ 14 TI-03-79-01 |
| 7. ~~AUTHOR(s)~~ 10 Gilbert L. Varnell, Jack Reynolds, Shang-Yi Chiang | | 8. ~~CONTRACT~~ OR GRANT NUMBER(s) 15 DAAB07-76-C-8105 |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS Texas Instruments P.O. Box 225012 Dallas, Texas 75265 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS ~~2759631~~ |
| 11. CONTROLLING OFFICE NAME AND ADDRESS Technical Support Activity U.S. Army Electronics Research and Development Command Fort Monmouth, New Jersey 07703 ATTN: DELET-ID | | 12. ~~REPORT DATE~~ 11 Apr[redacted] [redacted]79 |
| | | 13. NUMBER OF PAGES 8 |
| 14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 12 13p. | | 15. SECURITY CLASS. (of this report) Unclassified |
| | | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

electron beam
e-beam resists
256-bit Bipolar RAM

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A significant number (117) of 256-bit bipolar RAMs have been fabricated utilizing all e-beam direct slice writing and plasma etching. These devices pass all dc and ac electrical specifications including operating speed. A previous lot had device characteristics that were slower than specification due to an improper oxide thickness. One slice yielded 40% at dc probe compared to a high of 26% on one slice for a parallel photoresist lot. However, the lot yield for the e-beam slices was only 7.4% compared to 17% for the parallel photoresist lot. The reduced e-beam yield was attributed to an operator error during plasma etching of the contact O.R. and was not due to e-beam direct slice writing. Another lot of material is in progress (at metal) with tighter plasma etching control to complete the device quantity (500) required for completion of the contract.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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# IC FABRICATION USING ELECTRON-BEAM TECHNOLOGY

**Ninth Quarterly Report**

**1 September 1978 – 1 December 1978**

**Dr. G. L. Varnell**
**Dr. S. Y. Chiang**
**Dr. J. Reynolds**



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# SECTION I
# PURPOSE

Electron-beam direct slice writing has the potential to revolutionize the semiconductor industry and consequently many key Army applications. The superior resolution, geometry control, and alignment capabilities of electron-beam technology make feasible the reduction of the chip size of present day IC devices by an order of magnitude or conversely the increase in complexity of present day IC devices by an order of magnitude while maintaining the same chip size. This work was undertaken to bring about lower cost, lower power, higher density ICs for Army SIGINT and ELINT applications.

The overall objective of the program is to implement e-beam writing technology for the fabrication of microcircuits. The technical and economic impact of electron-beam direct slice printing will be demonstrated on 256-bit bipolar RAMs. The elimination of mask masters, masks, and the masking process will eliminate the most significant source of yield loss. This will permit greater circuit design complexity and flexibility which will lead to lower device costs with increased reliability. The complete implementation program is divided into three tasks. Task A, Yield Improvement Through Direct E-Beam Writing, is directed toward developing the manufacturing technology required for e-beam writing with existing equipment and existing resist processes and demonstrating the yield benefits of this technique. Task B, Cost Reduction for E-Beam Writing Through High Speed Resist Implementation, is directed toward implementing identified high speed e-beam resists in order to significantly decrease cycle time and thus reduce the IC bar cost. Task C, Cost Reduction for E-Beam Writing Through Automatic Beam Diameter Control and Automatic Handling, is directed toward utilizing EBMIII's capability of computer-controlled beam size (large and small) on high density circuit ($\leq$0.1 mil) geometries. This program also included implementation of an automated handling system for slices to reduce cycle time and thus further reduce bar cost.

## SECTION II
## TECHNICAL DISCUSSION

### A. INTRODUCTION

During the past quarter, lots 106 and 107 were completed and tested. It is unfortunate, however, that process errors totally unrelated to e-beam lithography prevented these lots from having the required yield to complete the contract. Lot 106 yielded only 117 GEBs (good electrical bars) through both dc and ac test. It is significant, however, that one slice of this lot yielded 40% through the dc test and that the above 117 bars meet all ac and speed tests. Lot 107 had only one slice with adequate yield (36 bars) through the dc test. Of equal importance to the good bars obtained from these lots is uncovering the hazards that can occur in the plasma oxide etch system and the importance of proper metallization. As a result of the problems incurred with these two lots, extreme caution has been exercised in the processing of the next lot (110). It has been processed through contacts and hand probed. The results of the probe data indicate that this lot will be an excellent high yielding lot when completed early in the next quarter.

### B. DEVICE FABRICATION

Of the various lots processed to completion and tested this quarter, lot 106 was the most successful. Of the 17 slices which started in this lot, 12 were completed and probed with the HSM (High Speed Measurements System). The HSM is a probe system which performs functional and dc parametric measurements tests on the individual bars on the slice. Although the lot yield at this test was only 7.4% for 289 GEBs, it is significant that one slice had a yield of 40% for 130 GEBs. Table I lists the bar yield for each of the slices in this lot. As seen in the table, four slices had 0 GEBs, four slices had 16 GEBs or less, three slices had 37, 42 and 44 GEBs, respectively, and one slice had 130 GEBs. It should be noted that when an oxide etch is performed in the plasma reactor, as it was with this material, one slice is initially etched by itself as a pilot to determine the oxide etch lots. After this pilot slice is etched, the remaining slices are etched four at a time. Unfortunately when the contact O.R. (oxide removal) was performed on this lot, the reactor operator failed to record which slice had been used for the pilot or the grouping of the other slices as they were etched. Subsequent analysis of the low yielding slices revealed that many of the contacts had not been totally cleared of oxide which prevented the metal from forming contact with the silicon. Based on this fact and knowledge of the plasma etching system, it is evident that the slice which yielded 40% was the pilot slice. Similarly, it can be concluded that the four slices which yielded zero bars were etched together as were the four slices yielding 1, 4, 15, and 16 GEBs, and the three slices yielding 37, 42 and 44 GEBs. To prevent this unfortunate event, which is unrelated to e-beam lithography, from occurring again, an experienced technician will perform an inspection of every slice during and after each oxide etch for future lots. The photoresist lot which accompanied this e-beam lot had an overall yield of 17%, with the highest slice yield being 26%.

Table I. Lot 106 Yield Data

| Slice No. | GEBs HSM | GEBs NEM |
|---|---|---|
| 1 | 0 | 0 |
| 16 | 0 | 0 |
| 4 | 0 | 0 |
| 30 | 0 | 0 |
| 29 | 1 | 0 |
| 31 | 4 | 0 |
| 18 | 15 | 0 |
| 25 | 16 | 0 |
| 22 | 44 | – |
| 17 | 37 | 31 |
| 28 | 42 | – |
| 27 | 130 | 86 |
| 12 | 289 | 117 |

The highest individual slice yield for the e-beam material is nearly twice that for the photoresist material, which indicates the capabilities of e-beam lithography.

Lot 106 encountered further problems when the slices went through the diamond saw to cut at the 289 bars for packaging. For this lot, 2% Cu doped Al was used at metal evaporization to ensure adequate step coverage. As the slices were cut with the high-speed diamond saw, the coolant water reacted with the phosphorous-doped emitter oxide forming a dilute phosphoric acid which corroded the bonding pads. The rest of the leads pattern on the slice were protected with the silicon-nitride overcoat. This corrosion made bonding to the pads difficult to impossible. Slices 17 and 28 with 37 and 42 GEBs, respectively, were processed through the diamond saw and were at package bonding when this problem appeared. Tests with the NEM (numerical exerciser for memories) resulted in only 31 GEBs from these two slices which started with 79 GEBs from the HSM. The corroded pads severely reduced the NEM yield. A photograph of one of the corroded pads is shown in Figure 1. In the process of determining what was causing the corrosion, slice No. 22 with a potential of 44 GEBs was broken into several pieces and examined with a scanning electron microscope. After determining what was causing the corrosion, slice No. 27 was cut into individual bars by scribing with a diamond saw and then breaking the bars apart from one another. This process is referred to as scribe and break. From this slice, 86 GEBs were obtained from the NEM test of the 130 packaged. The loss at scribe and break was far less severe than the loss due to corrosion with the diamond saw. The net yield from this lot was then 117 GEBs which passed all required dc and ac tests.

As the problems with lot 106 were being analyzed, lot 107 was going to contact oxide removal as was its companion photoresist lot 7. To ensure the contacts were open, each slice was carefully inspected at the plasma etch station. After it was determined that all of the contacts were visually open, each slice was hand probed to determine the current gain, beta, of three transistors on each slice. This was to assure that the contacts were indeed electrically open. For comparison, the photoresist material, lot 7, was also hand-probed. The results of these measurements are shown in Table II. Since the desired beta range is 30 to 60, it is clearly evident from the data in Table II

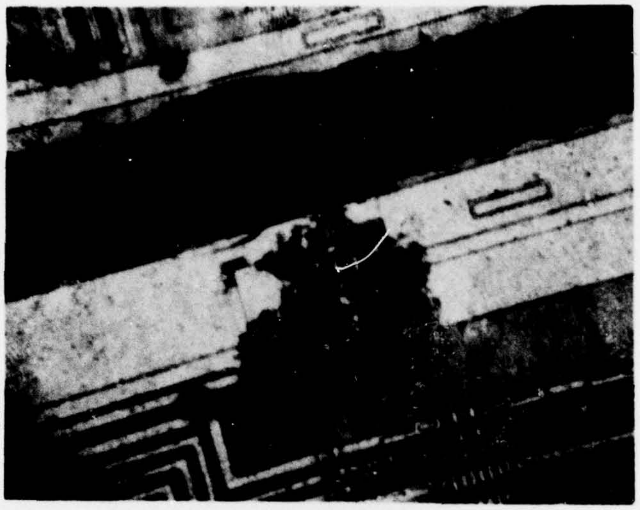

Figure 1. Corroded Bonding Pad

Table II. Current Gain as Measured on Three Devices on Each Slice

| E-Beam Lot 107 | | Photoresist Lot 7 | |
|---|---|---|---|
| Slice No. | Beta | Slice No. | Beta |
| 34 | 420-350-375 | 8 | 93-90-81 |
| 43 | 230-175-300 | 5 | 92-88-86 |
| 35 | CEO Short | 4 | 63-60-65 |
| 40 | CEO Short | 3 | 61-64-62 |
| 47 | 110-110-120 | 6 | 56-55-43 |
| 33 | 320-370-340 | 7 | 70-72-65 |
| 41 | 210-250-270 | 9 | 46-45-48 |
| 38 | 175-165-170 | 2 | 94-100-72 |
| | | 15 | 75-76-92 |
| | | 13 | 54-52-51 |
| | | 1 | 73-78-100 |
| | | 11 | 58-62-60 |
| | | 12 | 86-80-77 |
| | | 14 | 85-90-91 |

that lot 107 was not a good lot. It was, however, completed through leads with the hope of getting some good units. When probed with the HSM, the photoresist lot yielded 2227 GEBs for a lot yield of 29%. The e-beam lot yielded only 40 bars, 36 from slice 47 and 4 from slice 38. Slice 47 with its 12% yield should also have a number of bars that pass the NEM test. This slice will be held for processing with a future good lot through nitride deposition and final test. Since the photoresist lot and e-beam lot went through all furnace operations together, it was clearly an e-beam only process step which had caused the high current gain. It was suspected that at emitter O.R. something had gone wrong causing part of the base to be etched away. Since the base depth is only 1.0 $\mu$m deep, it would not require much removal to cause the current gain to go high. To verify this, an e-beam slice was stripped, sectioned through the emitter and examined with a scanning electron microscope (SEM). The results of this investigation are shown in Figure 2. As seen there for the e-beam material, 0.45 $\mu$m of silicon were removed from the 1.0-$\mu$m bars. This caused the standard emitter of 0.5-$\mu$m depth to penetrate the bars too deeply, causing high current gains and emitter-to-collector shorts. This excessive removal of silicon at emitter O.R. occurred in the plasma etch machine. The exact cause cannot be determined in retrospect since any one of several factors could have caused it. It is highly suspect that the supply of $C_5F_{12}$ was depleted during the course of emitter O.R., leaving only $CF_4$ in the reactor. This would have caused rapid etching of exposed silicon. Actions must be taken to correct this apparent operator error.

The next e-beam lot in the line is lot 110 and it is accompanied by the photoresist lot 10. To gain a tighter control on this lot the photoresist material was plasma etched simultaneously with the e-beam material. This fashion of etching was performed at emitter and contact O.R. for this lot. To be assured that none of the base was etched away at emitter O.R., as it was with lot 107, an e-beam slice was sectioned and examined with the SEM. The results are shown in Figure 3. For this examination, the oxide was not stripped from the slice. As seen in this photograph, none of the silicon had been removed from the emitter window into the base. After processing through contact and visually examining every slice to be certain all the contact windows were open, each slice was hand-probed. The results of this probe test for current gain, beta, are shown in Table III for the e-beam material and the photoresist material. As seen in the table, current gain for units with this run of material is precisely what it should be. This material has been sent on to metallization and will be completed early in the next quarter.

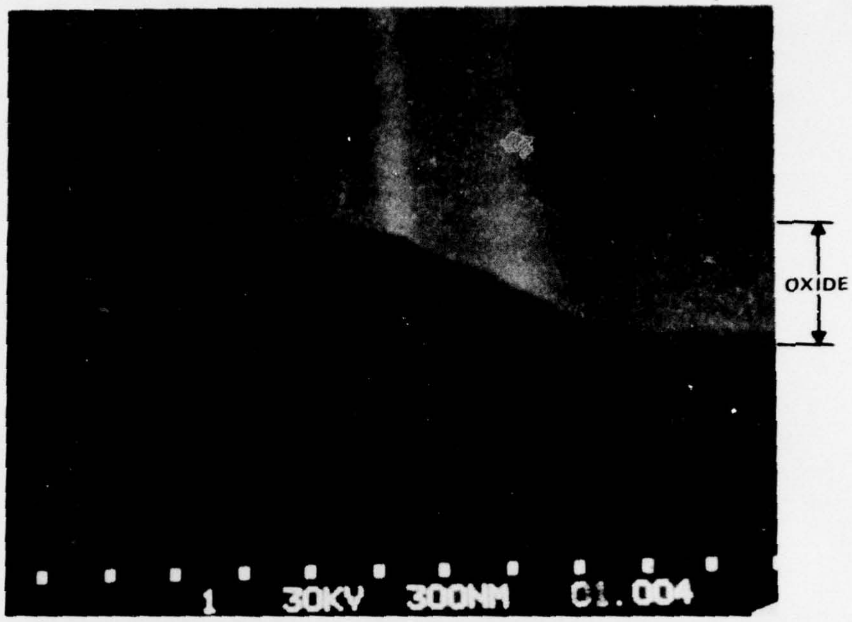


Figure 2. Cross Section of E-Beam Slice at Emitter O.R. with Oxide Stripped – Lot 107

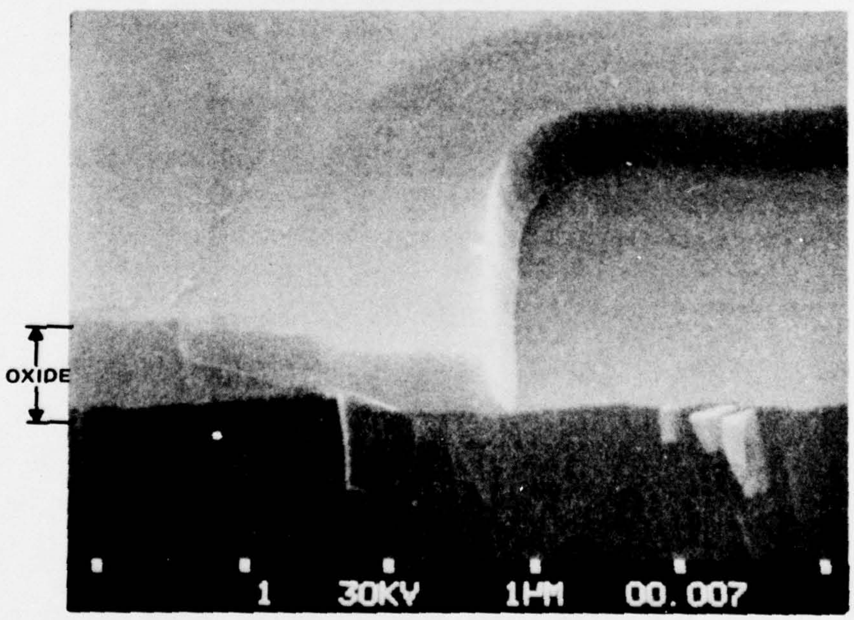


Figure 3. Cross Section of E-Beam Slice from Lot 110 at Emitter O.R. Oxide was not Stripped

Table III. Current Gain as Measured on Three Devices on Each Slice

| E-Beam Lot 110 | | Photoresist Lot 10 | |
|---|---|---|---|
| Slice No. | Beta | Slice No. | Beta |
| 2 | 70-70-66 | 1 | 42-43-42 |
| 4 | 62-60-47 | 3 | 57-59-63 |
| 10 | 50-55-54 | 5 | 52-50-48 |
| 12 | 45-43-47 | 7 | 48-57-65 |
| 14 | 46-47-46 | 9 | 49-54-50 |
| 16 | 44-45-44 | 11 | 55-56-58 |
| 22 | 45-47-45 | 13 | 65-53-54 |
| 24 | 52-52-48 | 15 | 52-55-50 |
| 26 | 34-47-50 | 17 | 44-48-42 |
| 28 | 50-53-48 | 19 | 54-57-58 |
| 30 | 42-48-48 | 21 | 53-52-50 |
| 32 | 50-51-53 | 23 | 76-65-61 |
| | | 27 | 54-57-56 |
| | | 31 | 58-65-68 |

## SECTION III
## MANPOWER

The following professionals worked on this program 1 September 1978 – 1 December 1978. The percentage of time worked is also shown.

| | |
|---|---|
| Dr. G. L. Varnell | 10% |
| Dr. J. L. Bartelt | 10% |
| Dr. S. Y. Chiang | 100% |
| Dr. R. A. Owens | 10% |
| Dr. J. Reynolds | 50% |
| Dr. R. A. Robbins | Consultant |
| Mr. C. D. Winborn | Consultant |

In addition, three technicians worked on the program.